Methods for variable time-delay estimation in industrial data

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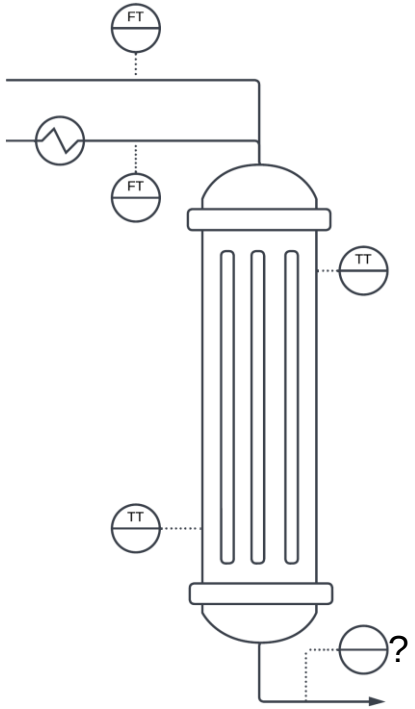
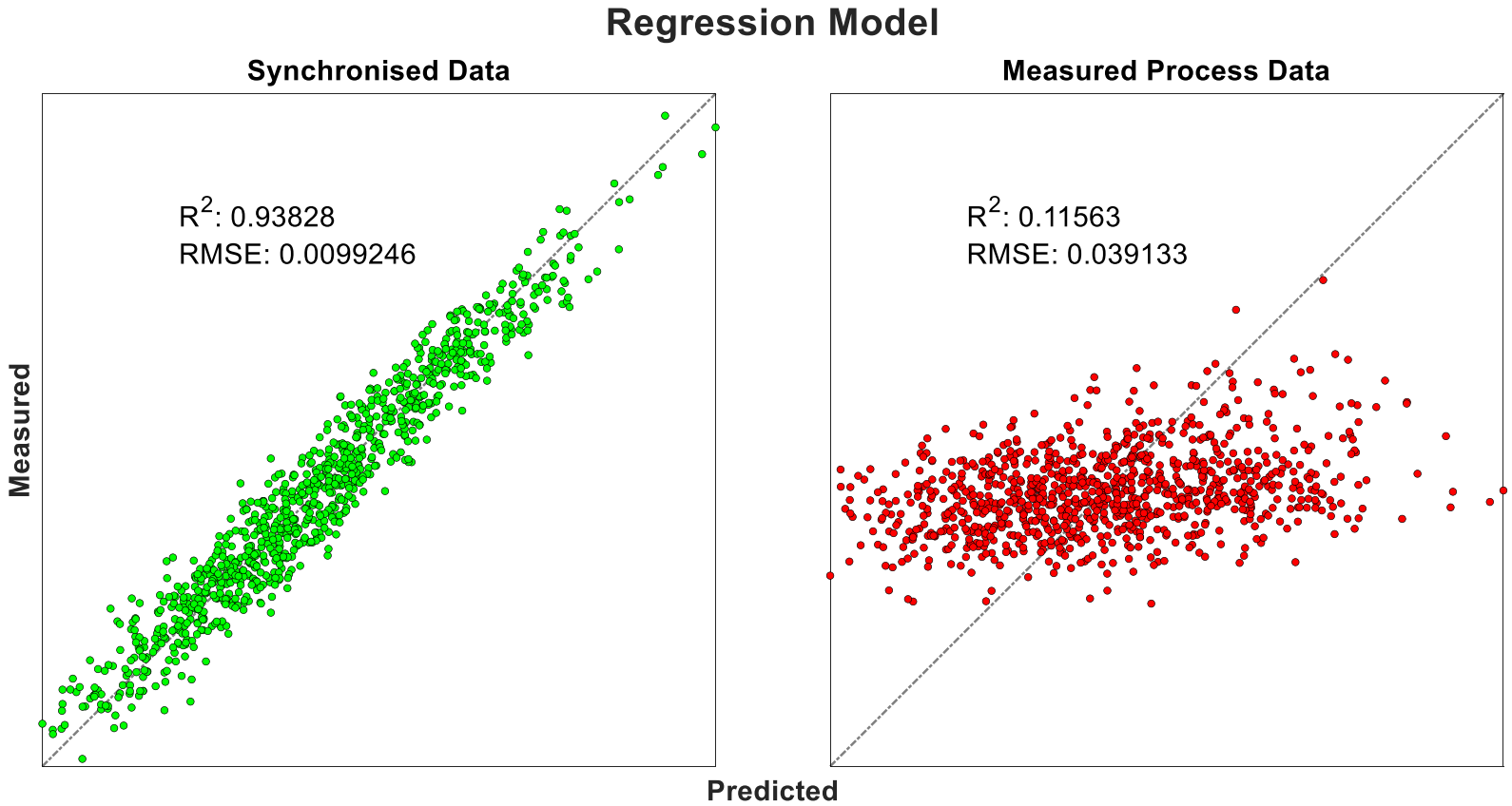
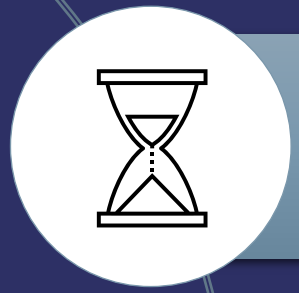
Have you ever…

Not so imaginary data story





Presentation Overview



What is variable time-delay

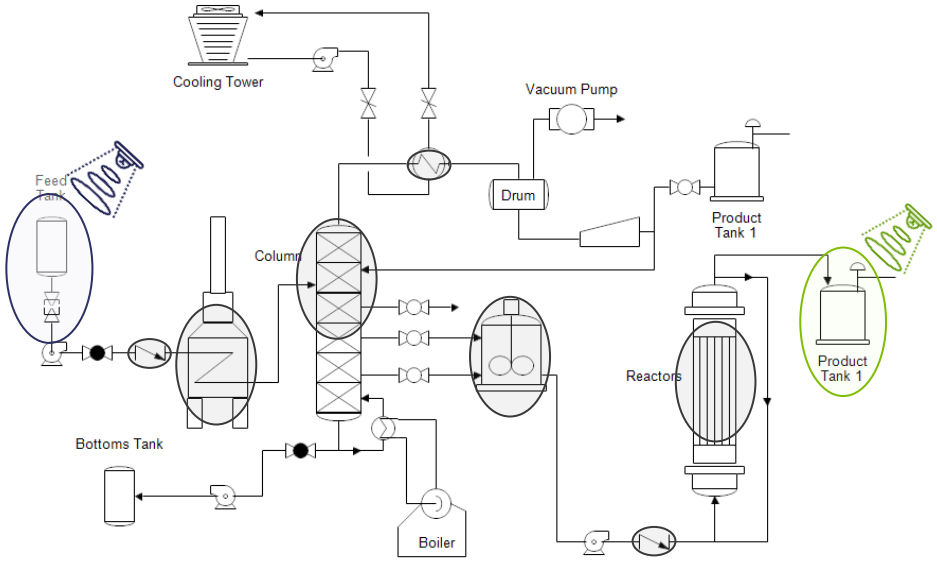
How do you estimate variable time-delay

Use Case

Variable time-delay estimation
Synchronisation of process variables



$$\textbf{\textit{Product quality}} = function(\text{raw material}, \text{processing})$$



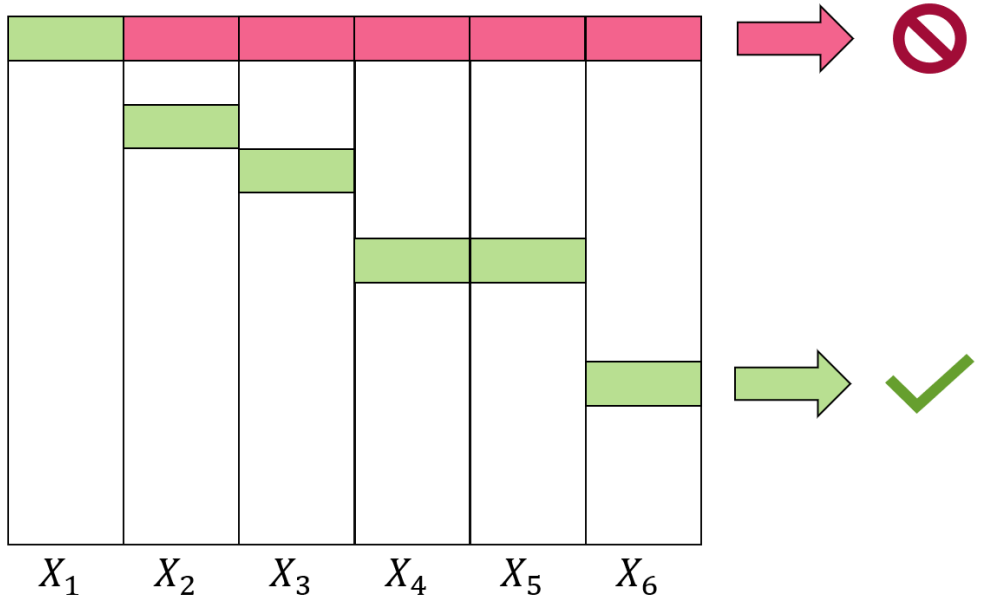
- Variable time delay is structural to most *continuous* processes.

- Data acquisition is *simultaneous*, process flow is *not*

Variable time-delay estimation
Approaching the time-delay estimation problem (1/2)

- Not tackling the issue will give *wrong* results

- How to solve the Variable time delay estimation problem?

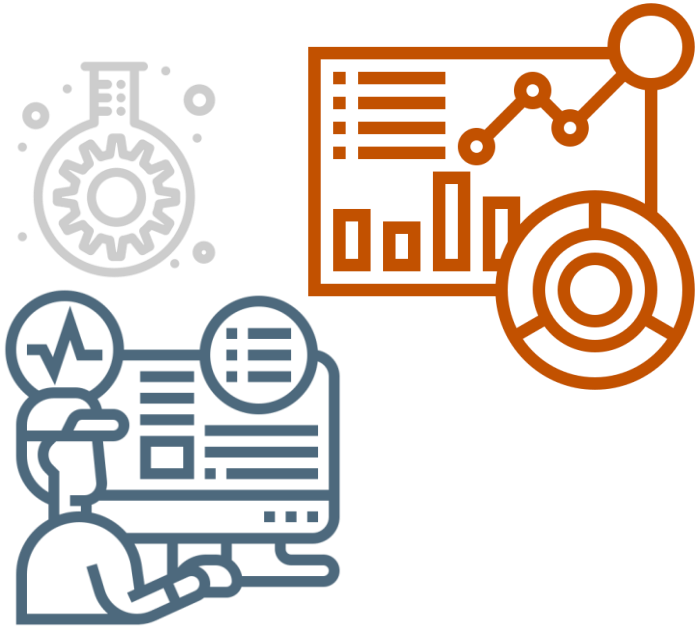


Variable time-delay estimation
Approaching the time-delay estimation problem (2/2)

- *Physical* variable time-delay estimation
  - Serious feasibility issues

- Consulting the *process operators*
  - Not precise enough

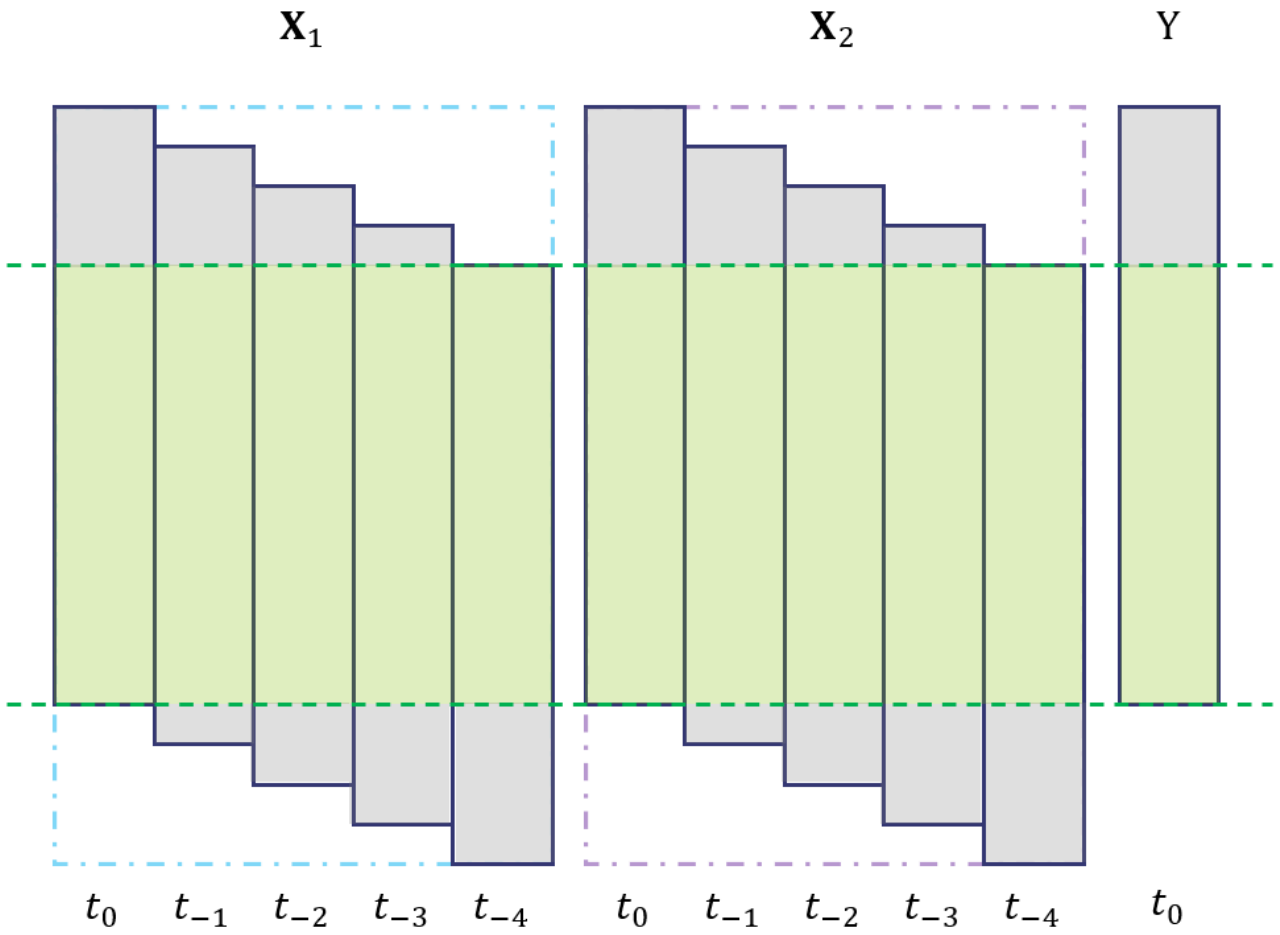
- A large amount of data-driven methods are available



Data-driven variable time-delay estimation how to:
Step 1: Incorporate all lags (1/3)

Steps for delay estimation

- Include all Lags in the dataset
  - Lag augmented predictor matrix
  - Lag augmented target matrix
  - Lag selection



Data-driven variable time-delay estimation how to:
Step 1: Incorporate all lags (2/3)

Steps for delay estimation

- Include all Lags in the dataset
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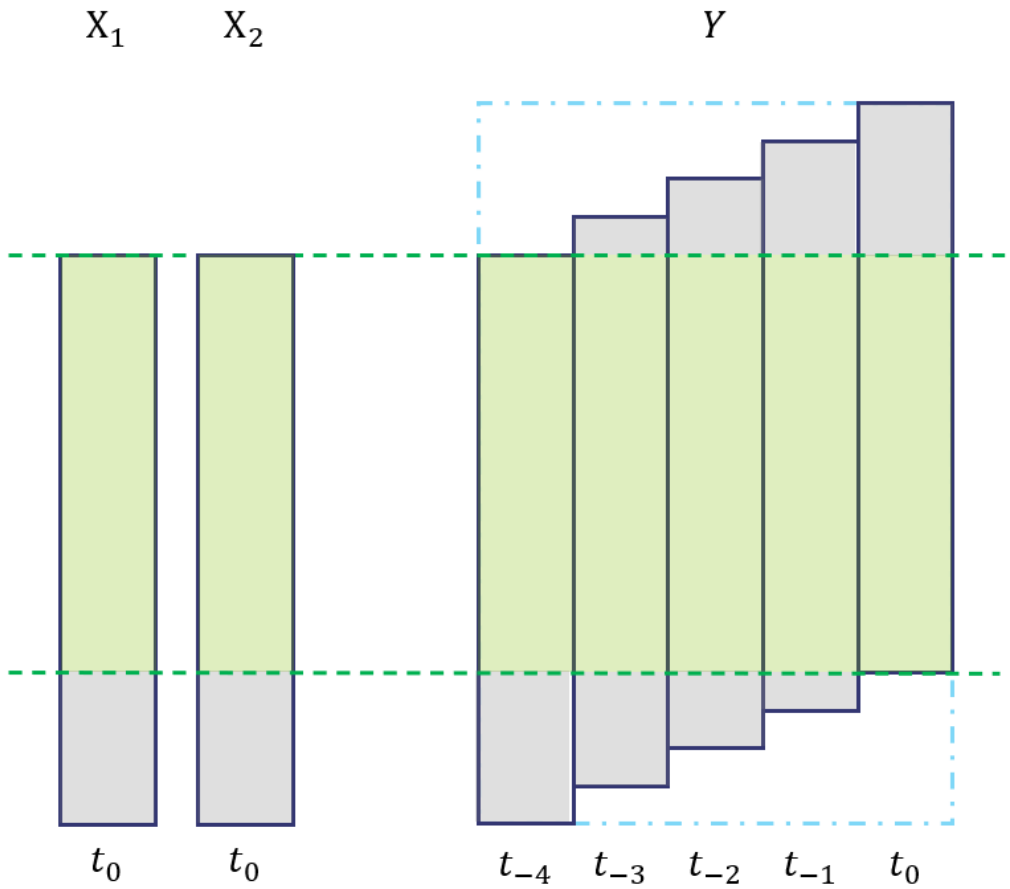
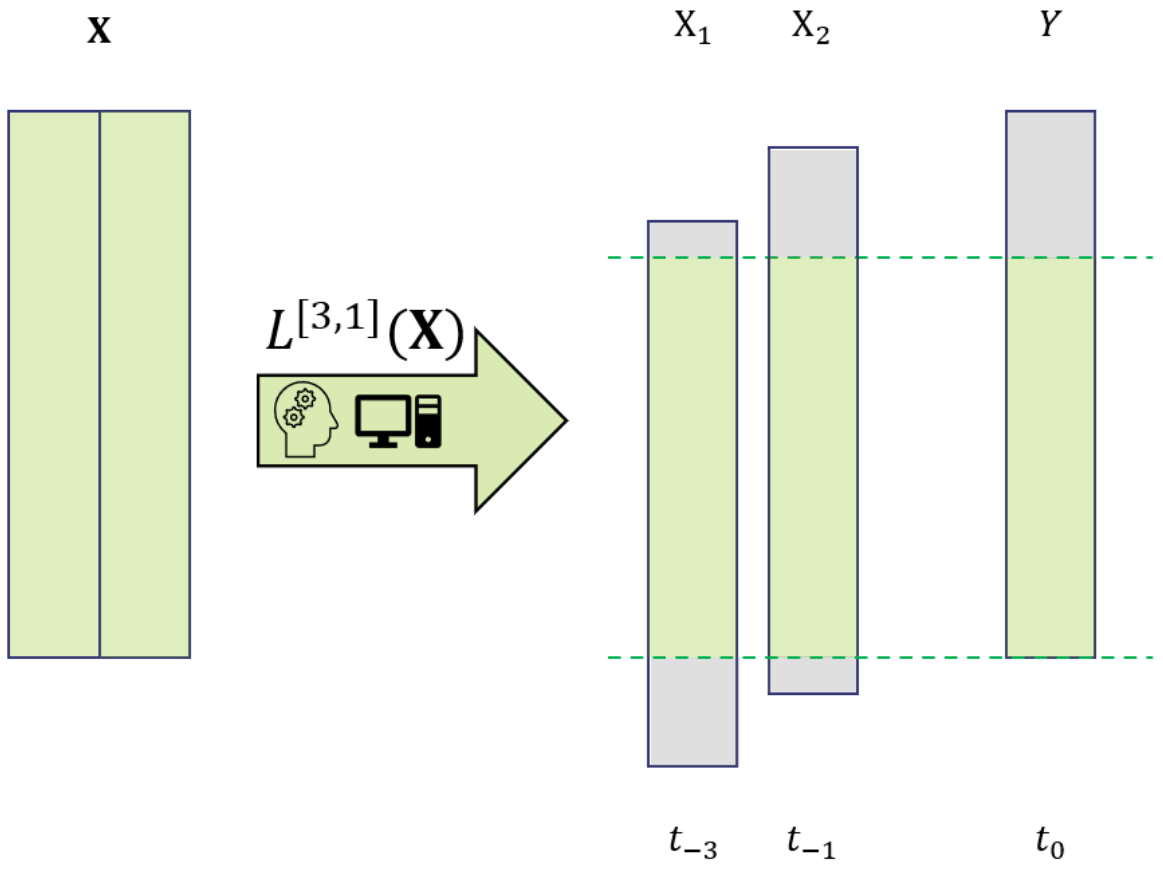


Data-driven variable time-delay estimation how to:
Step 1: Incorporate all lags (3/3)

Steps for delay estimation

- Include all Lags in the dataset
  - Lag augmented predictor matrix
  - Lag augmented target matrix
  - Lag selection

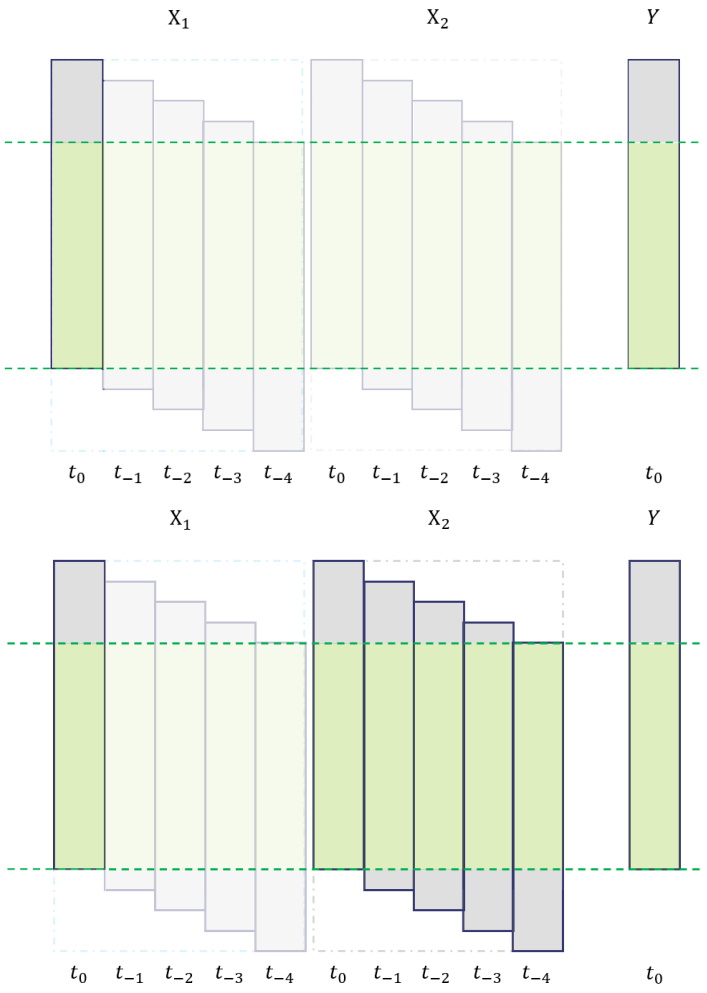


Data-driven variable time-delay estimation how to
Step 2: Identify the correct lags

Steps for delay estimation

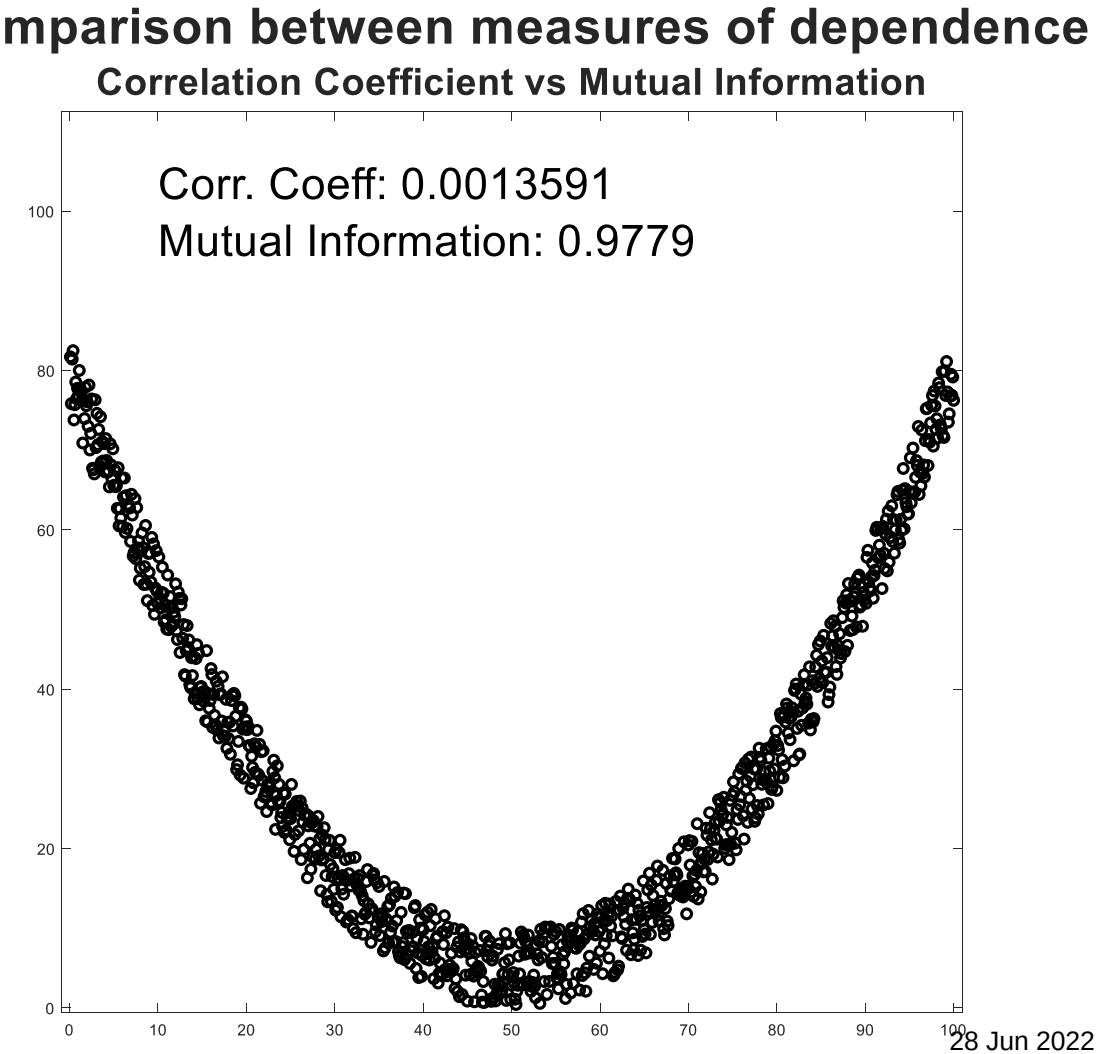
- Two possible approaches
  - Bivariate
  - Multivariate

- In all cases we can use
  - a MODEL
  - an INDEX



Data-driven variable time-delay estimation how to:
A word on Indices and Models

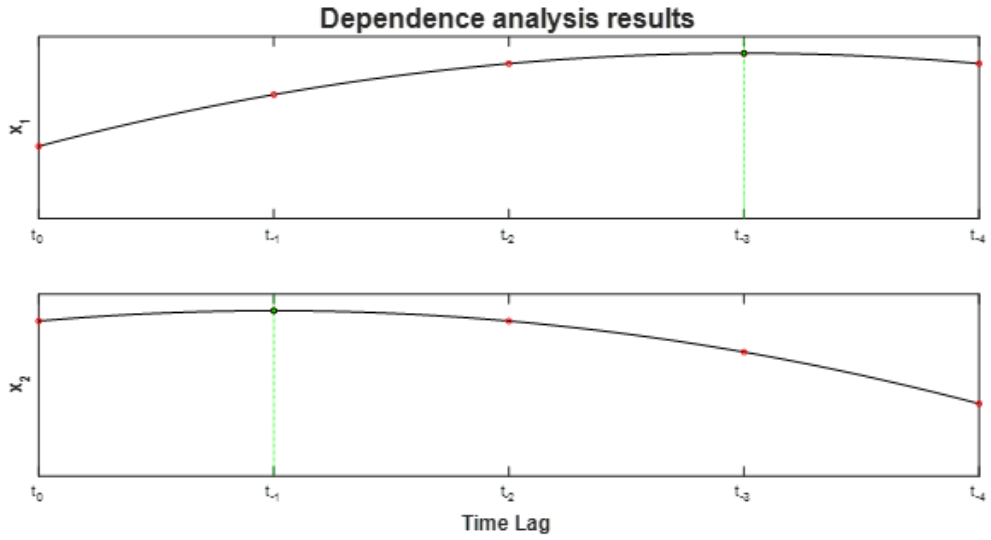
- Beware of nonlinearities!
- Identify the right type of model / index
- Compare different models / Indices

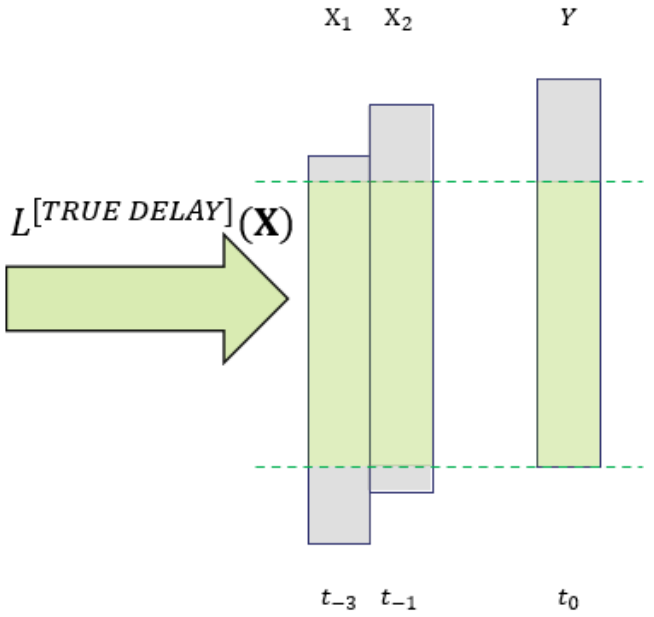


Data-driven variable time-delay estimation how to:
Step 3: Analyse the results

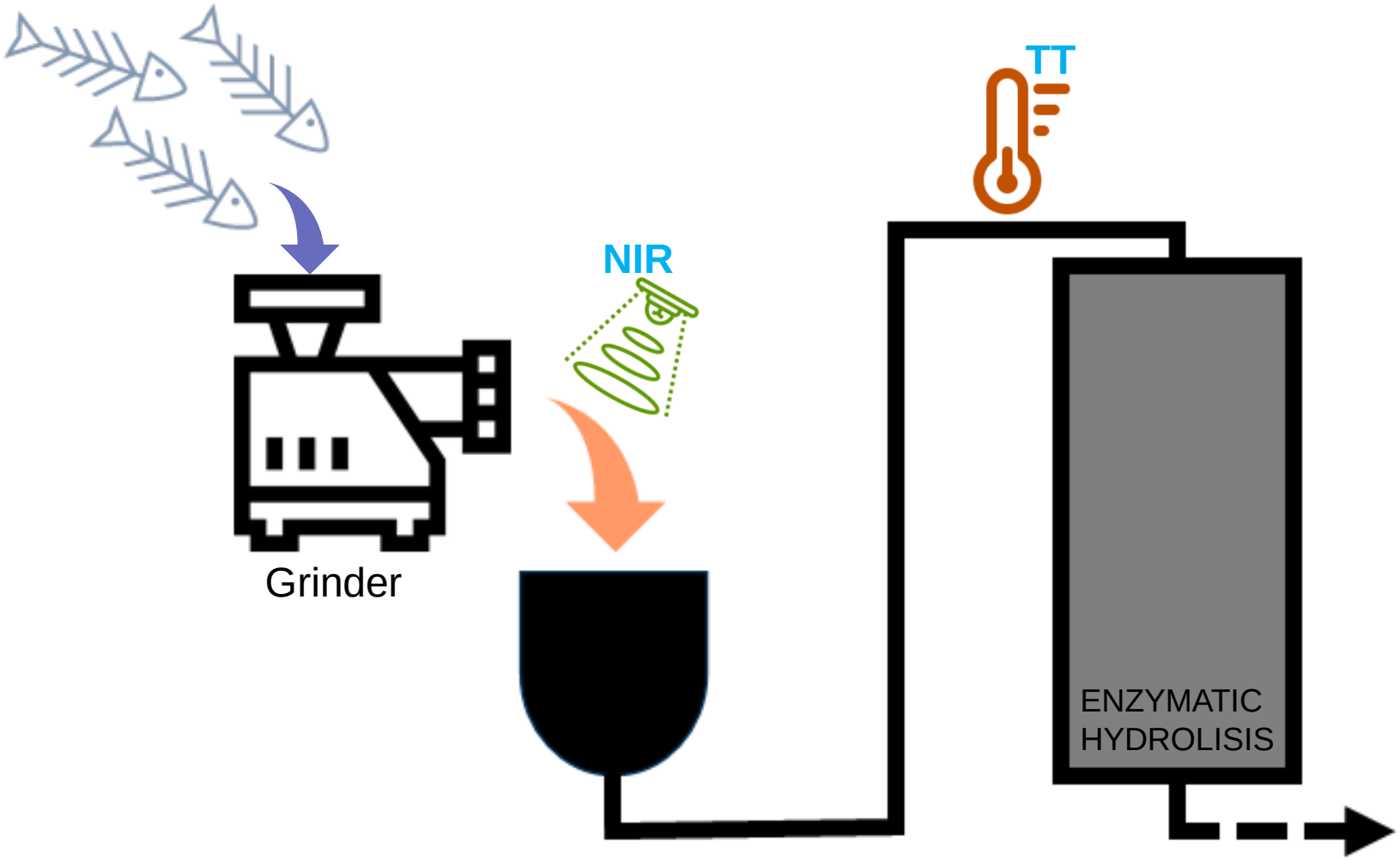
Steps for delay estimation

- Postprocess the results:
  - Identify max lag(s)
  - Rebuild the X matrix incorporating only the correct lags
- Proceed with further analysis



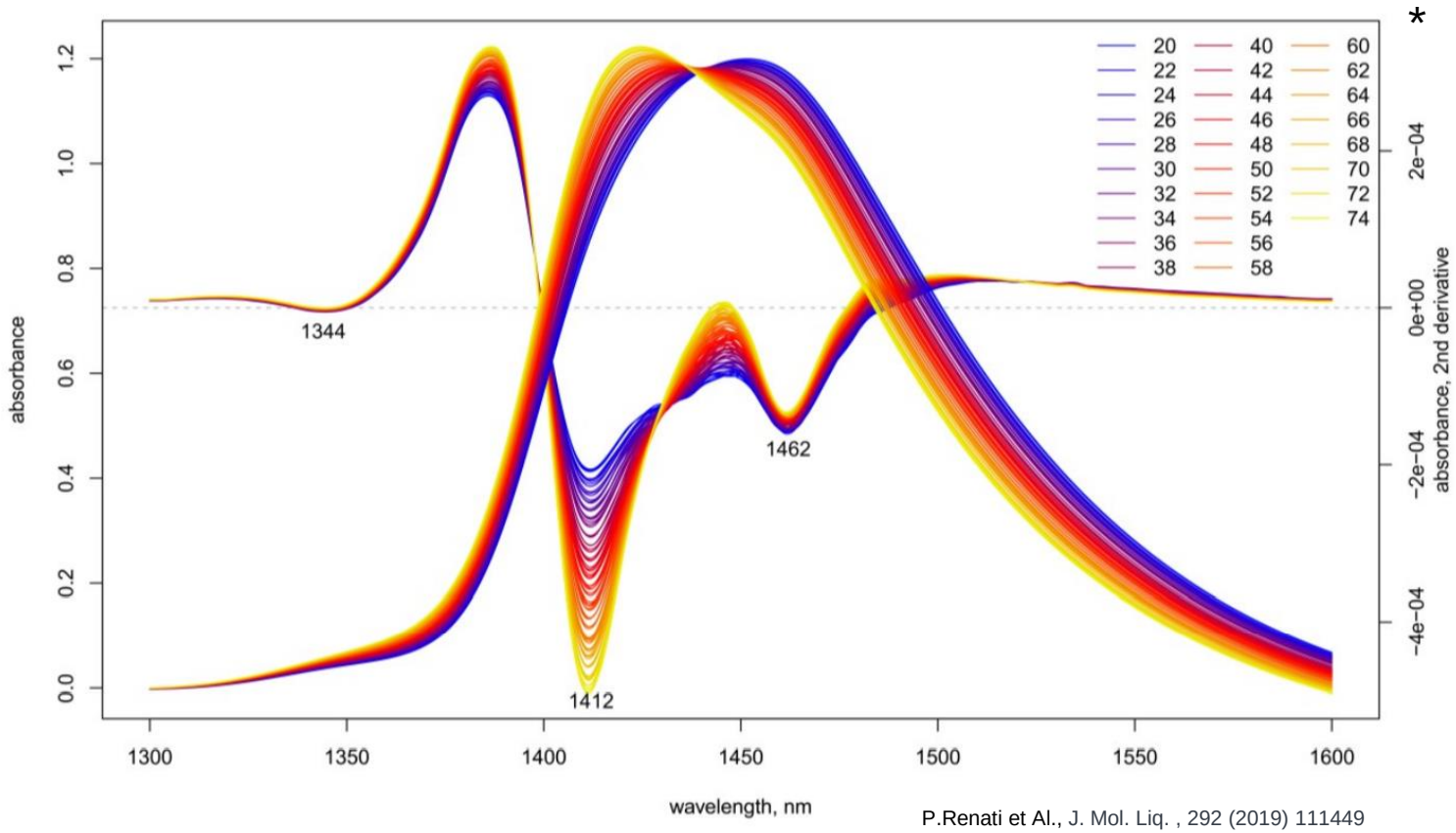


Industrial case:
In-Line NIR system @ Biomega



Industrial case:
Temperature and NIR (1/2)

- NIR measures light absorption on a sample
- With temperature the absorption changes
- NIR is an expensive thermometer

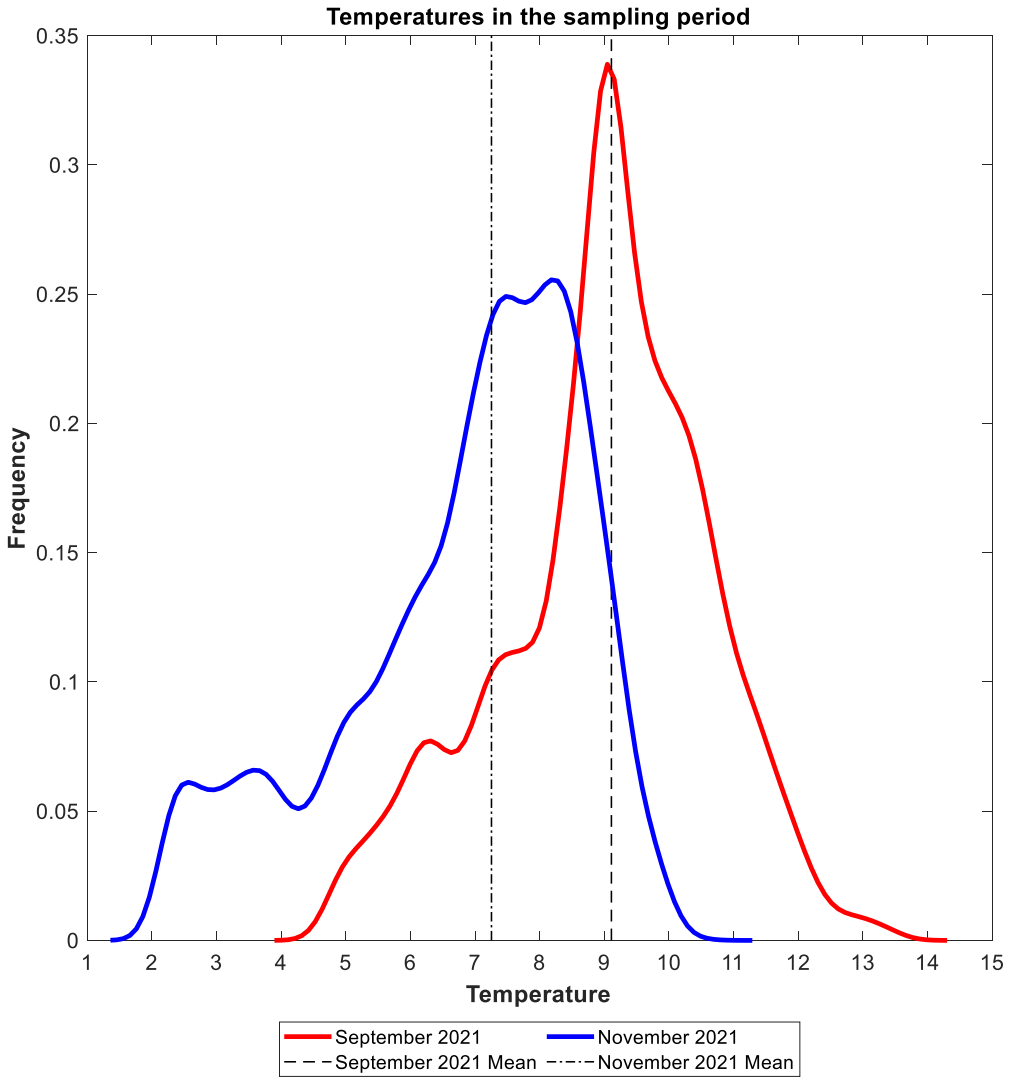


P.Renati et Al., J. Mol. Liq. , 292 (2019) 111449

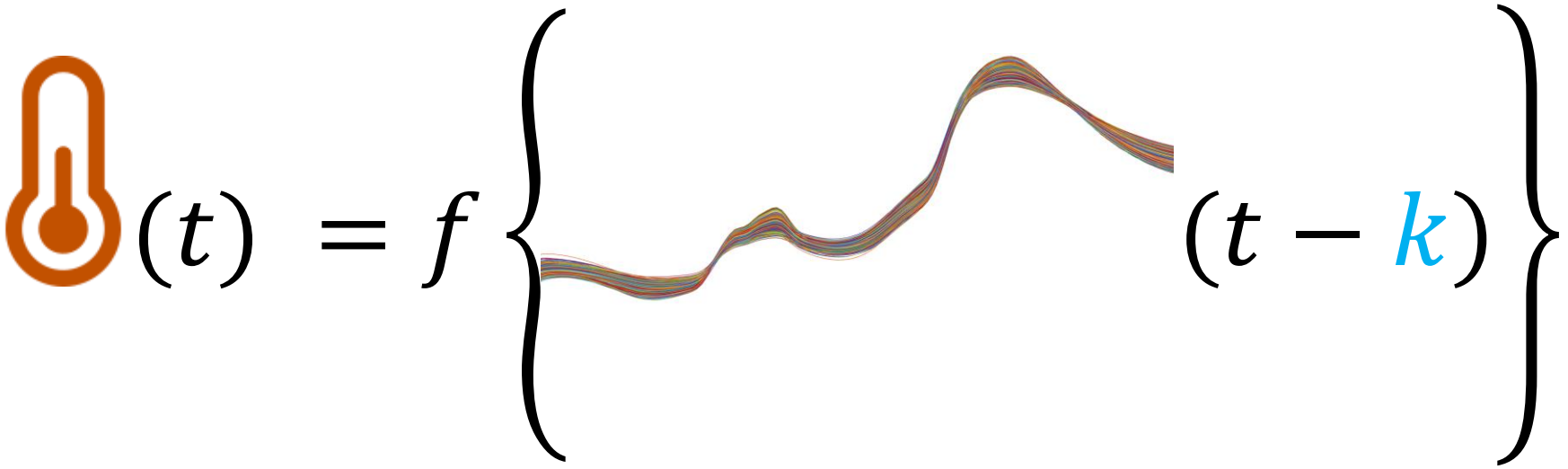
Industrial case:
Temperature and NIR (2/2)

- Great range of temperatures

- Calibration could be made more robust



Industrial case:
Solving the Time delay estimation problem



- For which *k* the relationship is the *strongest?*

- Compare four techniques

Industrial case:
Choice of techniques

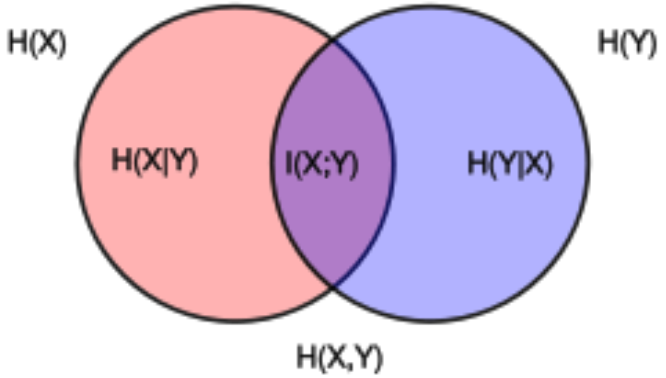
	INDEX	MODEL
Augmented matrix	Correlation Coefficient	PLS – Selectivity Ratio
Lag Selection	Mutual Information	PLS – Goodness of Fit

- Different kind of approaches tested
  - Bivariate
  - Multivariate

- Different parameters tested
  - Mutual Information, *number of neighbors*
  - PLS, *number of components*

Industrial case:
Techniques Explanation

- Mutual Information – I(**X**, Y)
  - Decrease in the uncertainty (entropy) of Y by knowing **X**
  - Distance between $P(\boldsymbol{X}, Y)$ and $P(\boldsymbol{X})P(Y)$



- Zero iif **X** and Y are independent

- Concept formulated for discrete signals
  - Must be *estimated* for continuous signals

Industrial case:
Interpreting the results

	t_0	t_{10}	t_{20}	t_{30}	t_{40}	t_{50}	t_{60}	t_{70}	t_{80}	t_{90}	t_{100}	t_{110}	t_{120}	t_{130}	t_{140}	t_{150}	t_{160}	t_{170}	t_{180}	t_{190}	t_{200}
Correlation Coefficient																					+
PLS – Selectivity Ratio									+						++					++	
PLS – R^2 of Cross Validation															+	+	++	+			
Mutual Information																+++	++				
Total									+						+++	++++	++++	+		++	+

- Some techniques are less robust

- The expected delay between NIR and Temperature is 140/160 seconds

Variable Time Delay estimation:
take-home points

- Variable Time-delay needs to be accounted for

- Many available methods

- No Free Lunch
  - there are *no catch-all methods*

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Thanks for your attention!

Time Delay Estimation

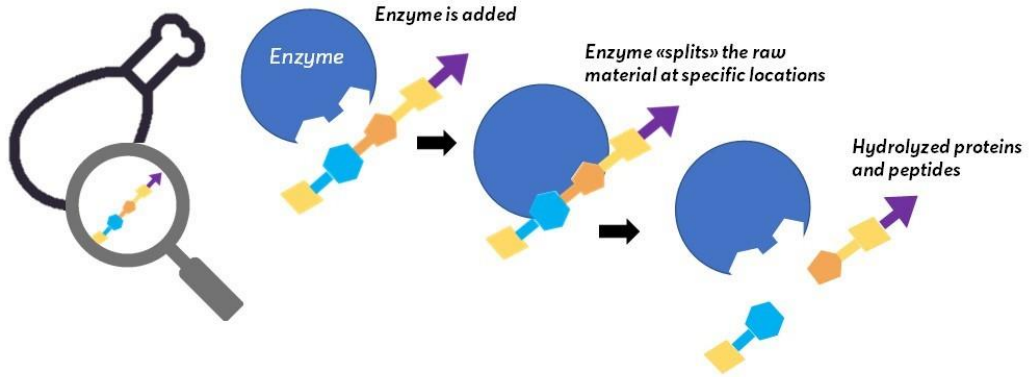
Feature Selection and Time Delay Estimation

- Feature selection and time delay estimation have a lot of common ground
  - Time delay estimation could be seen as a particular case Feature Selection on the lagged matrix

- Characteristics of time delay estimation
  1. Known number of variables to search for
  2. Same process generates all the lagged versions of a variable
     - There should be a clear maximum point in the dependence measurements vector
  3. The number of variables to target dramatically increases compared to the original Feature selection problem
     - l possible states for m variables→ $C^R(\mathrm{m},\mathrm{l}) = \frac{(m+l-1)!}{m!(l-1)!}$
     - Search strategies need to be further optimized for the methods to be applied

Industrial case:
In-Line NIR system @ Biomega

- Innovative company
- Extracts protein from fish rest raw material
- Sells to Human and animal feed market



Extra Slides End